ANSWERS: pH and pKa

1. Hydrofluoric acid is a stronger acid/more acidic/dissociates more because it has a smaller pK_a (larger K_a) than hypochlorous acid.
So HF will therefore have a higher $[H_3O^+]$. As $[H_3O^+]$ increases, the pH decreases, so HF will have a lower pH than HOCl.
(pH HF = 2.09, HOCl = 4.27)

2.
$[H_3O^+] = 10^{-11.8} = 1.58 \times 10^{-12}$

$$K_a = \frac{[CH_3NH_2][H_3O^+]}{[CH_3NH_3^+]}$$

$$= \frac{[CH_3NH_2][H_3O^+]}{[OH^-]}$$

$$2.29 \times 10^{-11} = \frac{[CH_3NH_2] \times (10^{-11.8})^2}{1 \times 10^{-14}}$$

$$[CH_3NH_2] = \frac{(2.29 \times 10^{-11}) \times (1 \times 10^{-14})}{(10^{-11.8})^2}$$

$= 0.0912$ mol L^{-1}

OR

$$[OH^-] = \frac{K_w}{[H_3O^+]} = \frac{10^{-14}}{10^{-11.8}}$$

$= 6.31 \times 10^{-3}$ mol L^{-1}

$$K_b = \frac{[OH^-]^2}{[CH_3NH_2]}$$

$$4.37 \times 10^{-4} = \frac{(6.31 \times 10^{-3})^2}{[CH_3NH_2]}$$

$$[CH_3NH_2] = \frac{(6.31 \times 10^{-3})^2}{4.37 \times 10^{-4}}$$

$[CH_3NH_2] = 0.0912$ mol L^{-1}

3. a) $HCl < CH_3NH_3Cl < CH_3NH_2$
HCl, a strong acid, reacts completely with water to form 1 mol L^{-1} H_3O^+ and hence a low pH.
$HCl + H_2O \rightarrow H_3O^+ + Cl^-$
CH_3NH_3Cl dissociates completely in water to form $CH_3NH_3^+$ and Cl^-. $CH_3NH_3^+$, a weak acid, partially reacts with water to form less than 1 mol L^{-1} H_3O^+ and hence a higher pH than HCl.
$CH_3NH_3Cl \rightarrow CH_3NH_3^+ + Cl^-$
$CH_3NH_3^+ + H_2O \rightleftharpoons CH_3NH_2 + H_3O^+$
CH_3NH_2, a weak base, partially reacts with water to form OH^- ions. So there are more OH^- ions than H_3O^+ ions and the pH is thus high.
$CH_3NH_2 + H_2O \rightleftharpoons CH_3NH_3^+ + OH^-$

4.

$$K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$$

- $pH = pK_a + \log\frac{[base]}{[acid]}$

$$[H_3O^+] = \sqrt{1.74 \times 10^{-5} \times 0.0896} \text{ mol } L^{-1}$$

$$= 1.25 \times 10^{-3} \text{ mol } L^{-1}$$

$$pH = -\log[H_3O^+] = 2.90$$

5.

$HCOOH + H_2O \rightleftharpoons HCOO^- + H_3O^+$

$$K_a = \frac{[HCOO^-][H_3O^+]}{[HCOOH]}$$

$$10^{-3.74} = \frac{(10^{-2.78})^2}{[HCOOH]}$$

$[HCOOH] = 0.0151 \text{ mol L}^{-1}$

6.

$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

$K_a = 10^{-9.24} = 5.75 \times 10^{-10}$

$K_b = [OH^-]^2 / [NH_3] = K_w / K_a = 1.74 \times 10^{-5}$

$[OH^-] = \sqrt{(1.74 \times 10^{-5} \times 0.150)} = 1.61 \times 10^{-3} \text{ mol L}^{-1}$

$[H_3O^+] = K_w/[OH^-] = 6.19 \times 10^{-12} \text{ mol L}^{-1}$ pH = 11.2

7)

$K_a = 6.76 \times 10^{-4}$

$HF + H_2O \rightleftharpoons H_3O^+ + F^-$

Assume $[H_3O^+] = [F^-]$

$$K_a = \frac{[H_3O^+]^2}{[HF]} \quad \Rightarrow \quad [HF] = \frac{[H_3O^+]^2}{K_a}$$

$[H_3O^+] = 4.57 \times 10^{-3} \text{ mol L}^{-1}$

$[HF] = 0.0309 \text{ mol L}^{-1}$

8)

$HG + H_2O \rightleftharpoons G^- + H_3O^+$

OR

$HOCH_2COOH + H_2O \rightleftharpoons HOCH_2COO^- + H_3O^+$

$$K_a = \frac{[G^-][H_3O^+]}{[HG]}$$ (must have equilibrium arrow)

$[H_3O^+] = \sqrt{K_a} \times [HG]$

$K_a = 1.50 \times 10^{-4}$

$[H_3O^+] = 9.99 \times 10^{-3} \text{ mol L}^{-1}$

pH = 2.00

9)

$$K_a = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$$

$$[NH_4^+] = \frac{[H_3O^+]^2}{K_a} = \frac{(10^{-4.66})^2}{10^{-9.24}}$$

$$= \frac{(2.19 \times 10^{-5})^2}{5.75 \times 10^{-10}} = 0.832 \text{ mol L}^{-1}$$

10. $CH_3COOH + H_2O \leftrightarrow CH_3COO^- + H_3O^+$

$$K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$$

$$K_a = 1.74 \times 10^{-5}$$

$$K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$$

$$1.74 \times 10^{-5} = \frac{[H_3O^+]}{0.0500}$$

$$[H_3O^+] = 9.32 \times 10^{-4}$$

$$pH = -\log(9.32 \times 10^{-4}) = 3.03$$

11.

$HN_3(aq) + H_2O \rightleftharpoons H_3O^+(aq) + N_3^-(aq)$

$$K_a(CH_3COOH) = \frac{[H_3O^+]\,[N_3^-]}{[HN_3]}$$

pH = 2.6 so $[H_3O^+(aq)]$ = **2.51×10^{-3} mol L^{-1}** = $[N_3^-(aq)]$

p$K_a(HN_3)$ = 4.72, $K_a(HN_3)$ = **1.91×10^{-5}**

$$K_a(HN_3) = 1.91 \times 10^{-5} = \frac{(2.51 \times 10^{-3})^2}{x}$$

***x* = 0.331 ie [HN_3 (*aq*)] = 0.331 mol L^{-1}** (Allow 0.330 and 0.33)

12.

$$K_a(HOBr) = \frac{[H_3O^+]\,[OBr^-]}{[HOBr]} = 10^{-8.62} = \mathbf{2.40 \times 10^{-9}}$$

$[H_3O^+(aq)] = [OBr^-(aq)] = x$ mol L^{-1}

$$\frac{x^2}{0.0525} = 2.40 \times 10^{-9} \quad x = [H_3O^+(aq)] = 1.12 \times 10^{-5}$$

pH = 4.95 (allow 4.9 or 4.950)

13.

pH greater than 7.

Since citric acid is a weak acid the anion is weakly basic and will react with water to accept H^+ from water.

eg $Cit^{3-} + H_2O \leftrightarrow HCit^{2-} + OH^-$

Increase in $[OH^-]$ causes increase in pH.

14.

$NH_3(aq) + H_2O \leftrightarrow NH_4^+(aq) + OH^-(aq)$

As NH_4Cl dissolves $[NH_4^+]$ is increased. This causes the equilibrium to move to favour formation of reactants so that $[OH^-]$ is decreased. As $[OH^-]$ is decreased, $[H_3O^+]$ is increased and pH is decreased.